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Pre-Cooling Moderately Enhances Visual Discrimination during Exercise in the Heat

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Preferred Running Head: Pre-Cooling and Visual Discrimination

Abstract

Pre-cooling has been reported to attenuate the increase in core temperature, although, information regarding the effects of pre-cooling on cognitive function is limited. The present study investigated the effects of pre-cooling on visual discrimination during exercise in the heat. Eight male recreational runners completed 90 min of treadmill running at 65% $\dot{V}O_{2max}$ in the heat [32.4±0.9°C and 46.8±6.4% relative humidity (r.h.)] on two occasions in a randomised, counterbalanced crossover design. Participants underwent pre-cooling by means of water immersion (20.3±0.3°C) for 60 min or remained seated for 60 min in a laboratory (20.2±1.7°C and 60.2±2.5% r.h.). Rectal temperature (T_{rec}) and mean skin temperature (T_{skin}) were monitored throughout the protocol. At 30-min intervals participants performed a visual discrimination task. Following pre-cooling, T_{rec} (P=0.040; η_p^2=0.48) was moderately lower at 0 and 30 min and T_{skin} (P=0.003; η_p^2=0.75) lower to a large extent at 0 min of exercise. Visual discrimination was moderately more accurate at 60 and 90 min of exercise following pre-cooling (P=0.067; η_p^2=0.40). Pre-cooling resulted in small improvements in visual discrimination sensitivity ($F_{1,7}$=2.188; P=0.183; η_p^2=0.24), criterion ($F_{1,7}$=1.298; P=0.292; η_p^2=0.16) and bias ($F_{1,7}$=2.202; P=0.181; η_p^2=0.24). Pre-cooling moderately improves visual discrimination accuracy during exercise in the heat.

Key words: Core temperature, Cold water immersion, Cognitive function

Introduction

Major sporting events regularly take place in environmental temperatures exceeding 30°C, and competing in such conditions results in an increase in core temperature. Rising core temperatures appear to negatively affect physical (González-Alonso, Teller, Andersen, Jensen, Hyldig, & Nielsen, 1999) and cognitive (Gaoua, Racinais, Grantham, & El Massioui, 2011) performance. As a consequence, a potential factor inducing fatigue during exercise is hyperthermia (Nielsen, Hales, Strange, Christensen, Warberg, & Saltin, 1993). Furthermore, high ambient temperatures have generally been reported to have a detrimental effect on exercise performance, possibly as a consequence of increased cardiovascular strain (González-Alonso and Calbet, 2003), rather than glycogen depletion (Parkin, Carey, Zhao, & Febbraio, 1999). In addition, metabolic disturbances have been suggested to be less important during prolonged exercise in the heat as increased oxygen extraction compensates for the reduction in systemic blood flow (Nybo, 2008). Therefore, a high core temperature may reduce physical performance due to a reduction in the central drive from the nervous system to the active musculature (Nybo and Nielsen, 2001).

When investigating the effects of heat exposure on various cognitive tasks, the results have been mixed with simple cognitive tasks, such as single reaction time, not appearing to be impaired during exposure to heat (Gopinathan, Pichan, & Sharma, 1988; McMorris et al., 1999; Cian, Koulmann, Barraud, Raphel, Jimenez, & Melin, 2000; Cian, Barraud, Melin, & Raphel, 2001). In contrast, more complex perceptual-cognitive tasks have reported reduced working memory and retention of visual information when core temperature is increased to 38.5°C (Hocking, Silberstein, Lau, Stough, & Roberts, 2001). Therefore, it appears that cognitive task performance may significantly deteriorate when the total physiological and cognitive resources are insufficient for both the task and the thermal stress imposed (Hancock & Vasmatzidis, 2003; Baars, 1997). In addition, it has been reported that cerebral blood flow is reduced in exercising hyperthermic participants compared with normothermic participants (Nybo, Moller, Volianitis, Nielsen, & Secher, 2002). Such reductions in blood flow may reflect the availability of substrate and lead to a depletion of the available glycogen stores in the brain, and consequently, impaired cognitive performance.

A number of strategies have been shown to be effective in reducing thermoregulatory strain and improving physical performance when exercising in the heat (Kay and Marino, 2000). The principle of pre-cooling limits the increase in core temperature caused by a fixed exercise task or increases the margin to the maximal core temperature that can be tolerated by reducing the temperature of the core prior to exercise (Quod, Martin, & Laursen, 2006). Consequently, pre-cooling has been reported to attenuate the increase in core temperature and improve exercise performance (Lee and Haymes 1995; Booth, Marino, & Ward, 1997; Cotter, Sleivert, Roberts, & Febbraio, 2001; Clarke, MacLaren, Reilly, & Drust, 2011). However, information regarding the effects of pre-cooling on cognitive performance is limited (Clarke et al., 2011).

Therefore, this study investigated the effects of pre-cooling on visual discrimination, as a marker of cognitive performance, during exercise in the heat. Examining the effects of ambulatory exercise on visual performance may be particularly useful as when a visual secondary task is added to exercise, the need to manage two streams of visual information concurrently (one related to exercise, the other to the visual secondary task) may exceed the capability of the prefrontal cortex amplifying dual task costs (Beurskens & Bock, 2012) and therefore, making the overall task more complex (Taylor, Watkins, Marshall, Dascombe and Foster, 2016). Such responses have not however been examined in a hot environment, either with or without pre-cooling. Moreover, during and after exercise somatosensory and/or motor information linked to movement persists and generates somatosensory and visual conflicts (Hashiba, 1998) resulting in different responses to running depending on the type of cognitive test employed, with particular impacts on visual performance. A visual decimation task was employed in the present study because the ability to pick up relevant visual information is essential for effective performance in several domains (Williams, Janelle, & Davids, 2004). We hypothesise that pre-cooling will enhance visual discrimination, during exercise in the heat.

Methods

Participants

Following ethical approval by the university ethics committee and familiarisation, eight male recreational runners (mean±SD age: 28±6 years; height: 1.76±0.08 m; body mass: 72.6±12.5 kg; maximal oxygen uptake ($\dot{V}O_{2max}$): 53±6 ml·kg^{-1}·min^{-1}) completed 90 min of treadmill (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports & Medical GmbH, Germany) running at 65% $\dot{V}O_{2max}$ in the heat [32.4±0.9°C and 46.8±6.4% relative humidity (r.h.)] on two occasions in a randomised, counterbalanced crossover design. Participants provided written informed consent prior to commencing the study, which was approved by the local ethics committee and therefore has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Procedures

Participants abstained from caffeine, alcohol, and strenuous activity for 12 h, and recorded their dietary intake for 48 h before the initial experimental trial. This diet was then replicated before the subsequent experimental trial. A volume of 5 mL·kg^{-1} (363±63 mL) of water was consumed 2 h before arriving at the laboratory and an additional 7 mL·kg^{-1} (508±89 mL) of water was ingested *ad libitum* during exercise. All trials were performed at the same time of day to minimise the circadian variation in internal body temperature. On arrival at the laboratory nude body mass was recorded, a rectal probe was inserted, skin thermistors were attached to the belly of the pectoralis, triceps brachii, vastus lateralis, and gastrocnemius on the right side of the body (Ramanathan, 1964). A capillary blood sample was then drawn from the index finger for determination of blood glucose and lactate concentrations (*Biosen* HbA1c, EKF-diagnostic GmbH, Germany) in order to assess blood substrate availability and physiological stress. The change in body mass was calculated from the difference in nude body mass between pre- and post-exercise and values were corrected for the volume of fluid ingested, and urine output to calculate sweat loss and rate.

Pre-cooling Procedure

On one occasion, participants underwent a pre-cooling manoeuvre by means of water immersion for 60 min prior to exercise (P-C). Pre-cooling involved each participant being seated and submerged, except for the head and neck, in water (20.3±0.3°C) in order to avoid some of the comfort issues associated with cold water immersion (Quod et al., 2006). On leaving the water participants towelled and dressed and commenced the exercise protocol 10 min following the end of cooling. The second session involved remaining seated for 60 min in a laboratory where ambient temperature and relative humidity were 20.2±1.7°C and 60.2±2.5% respectively (CON). Heart rate (Polar RS400, Polar Electro Oy, Finland), rectal temperature (T_{rec}) and mean skin temperature (T_{skin}) were monitored throughout the protocol (1000 Series Squirrel Data Logger, Grant Instruments, Cambridge, UK) and mean weighted skin temperature was calculated according to the equation of Ramanathan (1964). At 30-min intervals throughout the exercise protocol participants performed a visual discrimination task and a measure of coincidence anticipation timing. Participants also rated their thermal sensation (ASHRAE, 2004) and comfort (ASHRAE, 2004) before and after the cooling procedure and at the completion of each 30 min of exercise. A further capillary blood sample was drawn at the same time point and rating of perceived exertion (RPE) (Borg, 1973) was recorded.

Visual Discrimination (Go / No-Go) Task

Prior to the first experimental trial, participants were familiarised with the cognitive measures employed in the protocol. Participants completed a test of visual discrimination modelled on one developed by Pontifex, Hillman, & Polich (2009) and previously used by Moore, Romine, O'Connor, & Tomporowski (2012). The test required participants to respond as quickly and accurately as possible to a 5.5 cm diameter circle that occurred on 12.5% of trials and not to respond to a 5.0 cm diameter non-target circle that occurred on 75% of trials, or a 2 cm distractor square that occurred on 12.5% of trials. The test consisted of 200 trials and required approximately four minutes to complete. Within the test, stimuli were presented for 300 ms with a 1000 ms inter-stimulus interval via open source experiment software (Mathôt, Schreij, & Theeuwes, 2012) at the centre of a computer monitor located on the treadmill in front of the participant. To complete the visual discrimination test for each trial, participants were asked to press a trigger button, with their dominant hand, when the target stimulus was presented. Visual discrimination test performance was calculated as recommended from signal detection theory (Green & Swets, 1974) and comprised of two measures. An error rate was calculated, where the stimulus was presented and the trigger was not pressed or when the non-target stimulus was presented and the trigger was pressed. Response times (ms) were also calculated indicating the time taken to respond when the target stimulus was presented. Following familiarisation, the coefficient of variation (%CV) was 3.5% and 8.2% for accuracy and response time respectively.

Statistical Analysis

Data are reported as the mean ± the standard deviation (SD). The Shapiro-Wilk test was applied to the data in order to assess for a normal distribution. All variables except sweat loss and rate were assessed using a two-way analysis of variance with repeated measures. Sweat loss and rate were assessed using a paired-samples t-test. Sphericity was analysed by Mauchly's test of sphericity followed by the Greenhouse-Geisser adjustment where required. Where any differences were identified, pairwise comparisons with Bonferroni correction were used in order to show where they lay. All statistical procedures were conducted using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp.). An alpha level of $P<0.05$ was considered statistically significant. Furthermore, effect sizes using partial eta squared (η_p^2) and Cohen's *d* were calculated, and defined as trivial, small, moderate and large (Cohen, 1992).

Results

Thermoregulatory Responses

The 60 min period prior to exercise resulted in a large decrease in T_{rec} and a moderate reduction in T_{skin} during pre-cooling compared with the relatively stable T_{rec} ($F_{2,14}$=4.765; P=<0.001; η_p^2=0.64; Figure 1a) and increased T_{skin} ($F_{2,16}$=12.295; P=0.025; η_p^2=0.41; Figure 1b) in the control condition. Furthermore, following pre-cooling, T_{rec} ($F_{1,7}$=6.375; P=0.040; η_p^2=0.48; Figure 1a) was moderately lower at 0 and 30 min of exercise compared with the control condition, as was T_{skin} at 0 min ($F_{1,7}$=20.897; P=0.003; η_p^2=0.75; Figure 1b). However, a large increase in T_{rec} ($F_{1,7}$=82.318; P<0.001; η_p^2=0.92) and T_{skin} ($F_{2,13}$=40.786; P<0.001; η_p^2=0.85) was observed as a consequence of running in the heat during both trials. In addition, only trivial differences in sweat loss (CON: 2.2±0.6 L, P-C: 2.1±0.4 L; t(8)=-0.484, *P*=0.642, *d*=0.02) and sweat rate (CON: 1.5±0.4 $L \cdot h^{-1}$, P-C: 1.4±0.3 $L \cdot h^{-1}$; t(8)=-0.350, *P*=0.735, *d*=0.12) were observed between trials.

Please insert Figure 1 near here

Visual Discrimination

A small improvement in visual discrimination (Table 1) was evident following pre-cooling compared with CON [sensitivity: ($F_{1,7}$=2.188; *P*=0.183; η_p^2 =0.24); criterion: ($F_{1,7}$=1.298; *P*=0.292; η_p^2 =0.16); bias: ($F_{1,7}$=2.202; *P*=0.181; η_p^2 =0.24)]. Furthermore, only trivial differences between conditions were observed for the mean response time during the visual discrimination task ($F_{1,7}$=0.001; *P*=0.979; η_p^2 =0.00; Figure 2a). However, visual discrimination was moderately more accurate in terms of correct identifications at 60 and 90 min of exercise following pre-cooling ($F_{1,7}$=4.688; *P*=0.067; η_p^2 =0.40; Figure 2b). In addition, only trivial trial order effects were observed for visual discrimination mean response time ($F_{1,7}$=0.290; *P*=0.607; η_p^2 =0.04) and accuracy ($F_{1,7}$=0.473; *P*=0.514; η_p^2 =0.06).

Please insert Table 1 near here
Please insert Figure 2 near here

Heart Rate and RPE

Despite large increases in heart rate (Table 2) between each time point ($F_{3,15}$=237.420; *P*<0.001; η_p^2 =0.98), there were only trivial differences between conditions ($F_{1,5}$=0.010; *P*=0.926; η_p^2 =0.00). A similar pattern was observed for RPE (Table 2), with only trivial differences between conditions ($F_{1,7}$=0.163; *P*=0.699; η_p^2 =0.02) and large increases during exercise between each time point ($F_{1,8}$=31.571; *P*<0.001; η_p^2 =0.82).

Please insert Table 2 near here

Subjective Responses

A large increase in thermal sensation was observed between each time point until 60 min of exercise ($F_{3,21}$=58.184; P<0.001; η_p^2 =0.89; Table 3). However, there were only trivial differences between conditions ($F_{1,7}$=1.235; P=0.303; η_p^2 =0.15). Thermal comfort (Table 3) followed a similar trend, with only trivial differences between conditions ($F_{1,7}$=1.217; P=0.306; η_p^2 =0.15) and the rating being moderately lower at 90 min of exercise compared the other time points, irrespective of trial ($F_{3,21}$=10.125; P<0.001; η_p^2 =0.59).

Please insert Table 3 near here

Metabolic Responses

Pre-cooling resulted in only trivial differences in blood glucose ($F_{1,7}$=0.073; P=0.795; η_p^2 =0.01) and lactate ($F_{1,7}$=1.125; P=0.324; η_p^2 =0.14) (Table 4). Overall there was a small reduction in blood glucose at 0 min of exercise when compared with -60 and 90 min of exercise ($F_{4,28}$=4.210; P=0.009; η_p^2 =0.38). Furthermore, a moderate increase in blood lactate concentration was observed at 30 and 60 min of exercise, compared with resting conditions ($F_{4,28}$=12.072; P<0.001; η_p^2 =0.63).

Please insert Table 4 near here

Discussion

The aim of this study was to investigate the effects of pre-cooling on a visual discrimination test during exercise in the heat. The key findings of the present study are that pre-cooling, via 60 min of cold water immersion, reduced core and skin temperature for approximately 30 min of running in the heat and moderately, although not significantly, improved the accuracy at 60 and 90 min, but not response time, during a visual discrimination task. Furthermore, pre-cooling had only trivial effects on markers of exercise intensity and subjective ratings of thermal sensation and comfort during exercise.

Pre-cooling resulted in moderate non-significant improvements in visual discrimination accuracy during exercise in the heat, although only a trivial non-significant effect on response time was found. Furthermore, pre-cooling resulted in small non-significant improvements in visual discrimination sensitivity, criterion, and bias. Few studies have examined the effect of pre-cooling on visual discrimination during exercise in the heat making it difficult to draw strong conclusions regarding the change in response accuracy between pre-cooled and control conditions in the current study. Some prior research examining passive heat exposure has reported a loss in accuracy in reaction time type tasks after heat exposure (Nunneley and Maldonado, 1983; Simmons, Saxby, McGlonem, & Jones, 2008). The suggestion has been made that maintaining attentional resources, such as that required in the visual discrimination task employed in the present study, creates a fatiguing mental load (Boksem, Meijman, & Lorist, 2005) that is related to a deterioration in cognitive performance (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2002). In thermo-neutral conditions such an effect is seen after 20-35 minutes depending on the task (Warm, 2008) and this timeframe is reduced in hot conditions (Gaoua et al., 2011). The results of this study would indicate that pre-cooling may offset this effect is consistent with Goaua et al., (2011), where head cooling during passive heat exposure offset reductions in cognitive performance. The rise in core temperature, due to heat stress, is associated with an increase in brain temperature (Siesjö, 1978), which has been shown to impair neuronal activity and/or brain dysfunction (Uno, Roth, & Shibata, 2003; Kiyatkin, 2005). Nybo (2012) proposed that during prolonged dynamic exercise brain temperature can be an influencing factor on motor performance, which is largely controlled by the arterial blood and general body core temperature response. Furthermore, it has been reported that cerebral blood flow is reduced in exercising hyperthermic participants compared with normothermic participants (Nybo et al., 2002). Therefore, the lower core temperature observed with pre-cooling may have, in part, resulted in a lower brain temperature and greater cerebral blood flow, contributing to the improved visual discrimination accuracy observed in the present study, as it has been shown that discriminatory tasks can be negatively affected by heat stress (Cain et al., 2000). Furthermore, executive control of attention has been shown to deteriorate linearly with a rise in core body temperature and non-linearly with longer passive heat exposure (Liu et al., 2015), suggesting that individuals perform “less effectively” when in a hot environment.

Pre-cooling significantly reduced core and skin temperature before exercising in the heat, and this trend remained for the first 30 min of running in the heat. This timeframe for the beneficial effects of pre-cooling, in terms of a reduced core temperature, is consistent with previous studies (Kruk, Pekkarinen, Harri, Manninen, & Hanninen, 1991; Lee and Haymes 1995; Bolster et al., 1999). In addition, evidence exists to support the use of cold water immersion as a pre-cooling intervention to improve endurance exercise performance in the heat (Jones, Barton, Morrissey, Maffulli, & Hemmings, 2012). The improved capacity for heat storage following pre-cooling has become one of the most prominent explanations for improvements in performance under such conditions (Quod et al., 2006). Furthermore, the reduced core and skin temperature associated with pre-cooling allows for a greater heat storage before core temperature reaches a level high enough to stimulate heat dissipation (Drust, Cable, & Reilly, 2000), reducing the physiological strain.

The reduced core temperature associated with pre-cooling allows for a greater heat storage before core temperature reaches a level high enough to stimulate heat dissipation (Drust et al., 2000), reducing the physiological strain. However, in the present study there was not a significant reduction in the heart rate and RPE during the pre-cooling trials. Thermal sensation and comfort only differed between trials immediately following the cooling procedure, similar to the findings of Bolster et al. (1999). Pre-cooling did not significantly affect total sweat loss or sweat rate during the run. This observation may be as a consequence of the amount of heat lost through the evaporation of sweat is largely determined by the metabolic heat production and the environmental heat load (Nielsen, 1996), which was the same for all trials. This observation was consistent with previous findings (Booth et al., 1997; Drust et al., 2000; Clarke et al., 2011). The similar blood glucose and lactate, heart rate and RPE, would also suggest similar physiological stress between trials.

The current study is not without limitations. Current evidence indicates that cold water immersion may be the most effective method of pre-cooling in order to improve endurance performance in hot conditions (Jones et al., 2012). However, due to issues such as time, cost, access and transportation, this may not be practical in an applied setting or situation where a number of individuals require cooling. Therefore, alternative pre-cooling methods may need to be considered. For example, the ingestion of 7.5 $g \cdot kg^{-1}$ of a flavoured ice slurry mixture effectively lowers core body temperature, and produced similar physical performance as observed with water immersion (Siegel, Maté, Watson, Nosaka, & Laursen, 2012). Furthermore, ice is relatively cheap and may represent a more practical alternative to whole body cold water immersion. However, further research is required in order to validate this hypothesis. Additionally, there is also a need to consider the efficacy of pre-cooling on cognitive performance using more cognitively demanding and ecologically valid tasks.

In conclusion, these results suggest that pre-cooling moderately improves visual discrimination accuracy during exercise in the heat. Therefore, pre-cooling has the potential to improve sporting performance in the heat by maintaining the athlete's ability to pick up relevant visual information. However, the effect of pre-cooling on cognitive performance in the heat may have different effects depending on the nature of cognitive task, and consequently, further investigation is required.

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